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Takahashi et al.

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(54) **BINARY POWER GENERATION SYSTEM AND STOPPING METHOD FOR SAME**

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PCT Pub. Date: **Aug. 16, 2018**

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(Continued)

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(58) **Field of Classification Search**
CPC F01K 23/04; F01K 25/10; F01D 17/08; F01D 21/00; F04D 15/00; F04D 29/66
See application file for complete search history.

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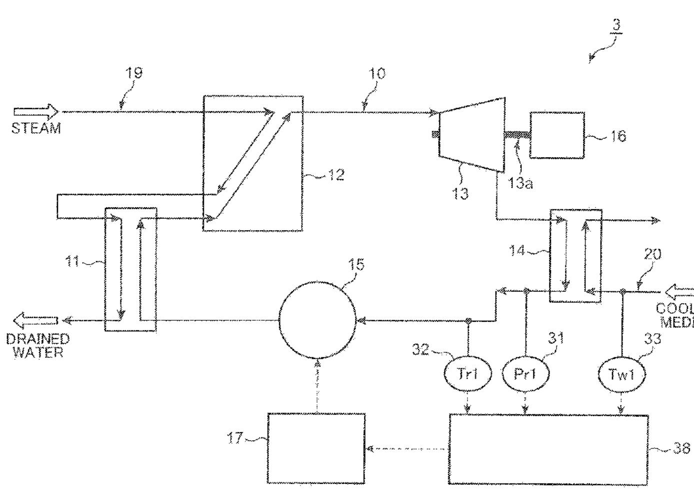
(57) **ABSTRACT**

A binary cycle power generation system includes a working fluid circulation line, an evaporator, an expander, an energy recovery apparatus, a condenser, and a pump. The pump includes a casing, a rotary shaft, and impellers. The casing is hollow and has an end wall at an end in a longitudinal direction. The rotary shaft has an axis extending in the longitudinal direction of the casing, is supported on the end wall, has at least a part that is in the casing, and rotates owing to a torque. The impellers are attached to the rotary shaft one after another in the longitudinal direction. The pump is arranged in such a way that the axis of the rotary shaft intersects a vertical direction.

5 Claims, 8 Drawing Sheets



(51) **Int. Cl.**

F01D 21/00	(2006.01)
F01K 25/10	(2006.01)
F04D 15/00	(2006.01)
F04D 29/66	(2006.01)

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FIG. 1

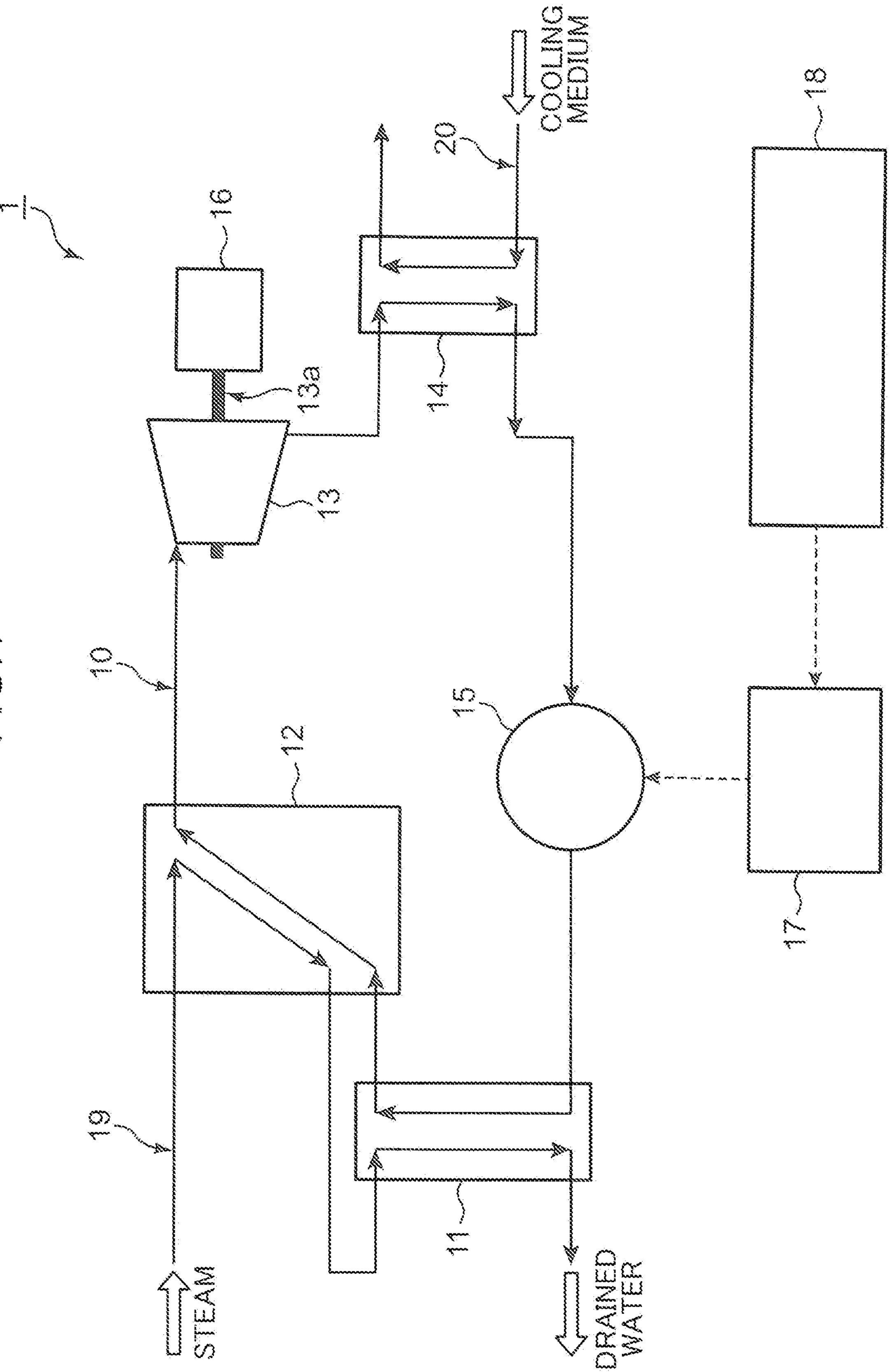

1
16
13a
13
14
20
COOLING MEDIUM
18
10
12
15
17
19
11
STEAM
DRAINED WATER

FIG.2

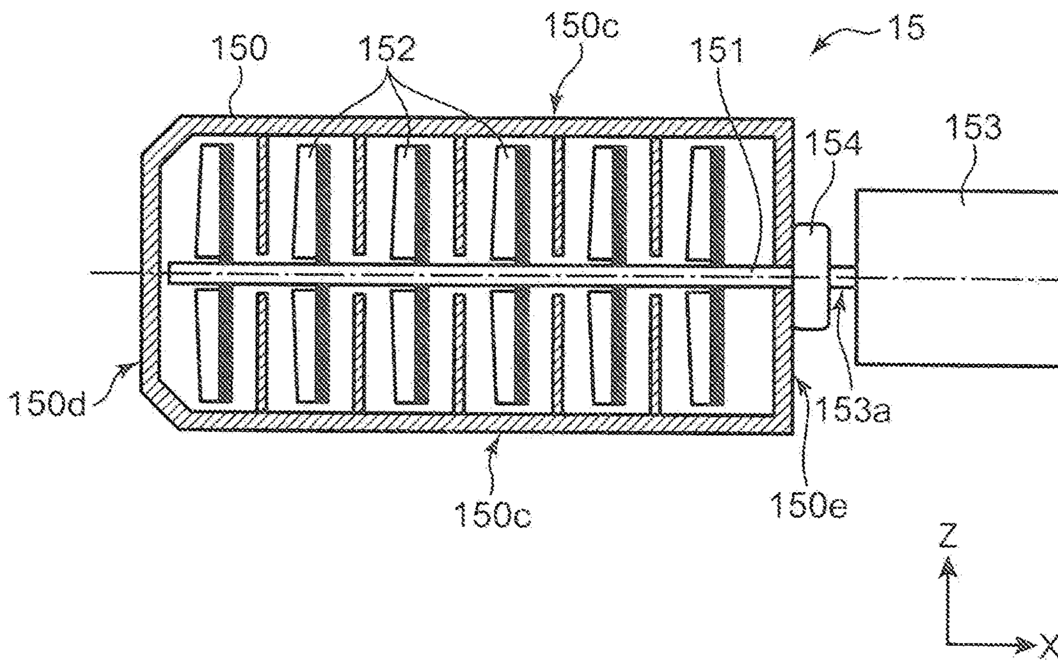


FIG.3

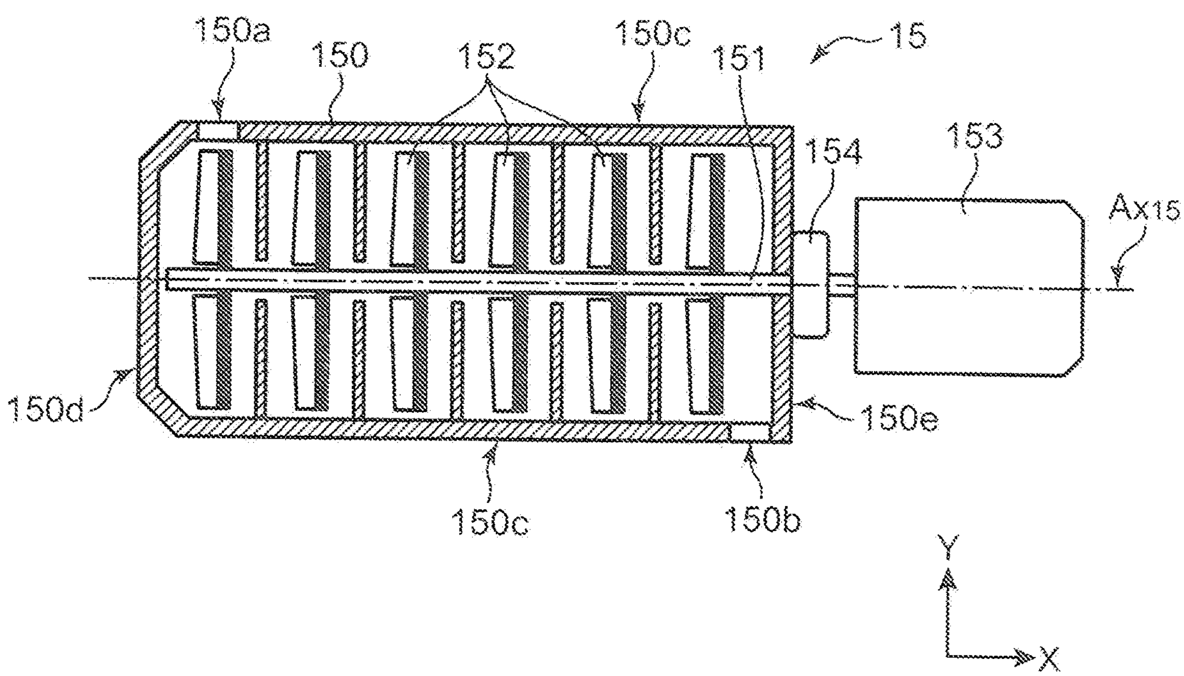


FIG.4

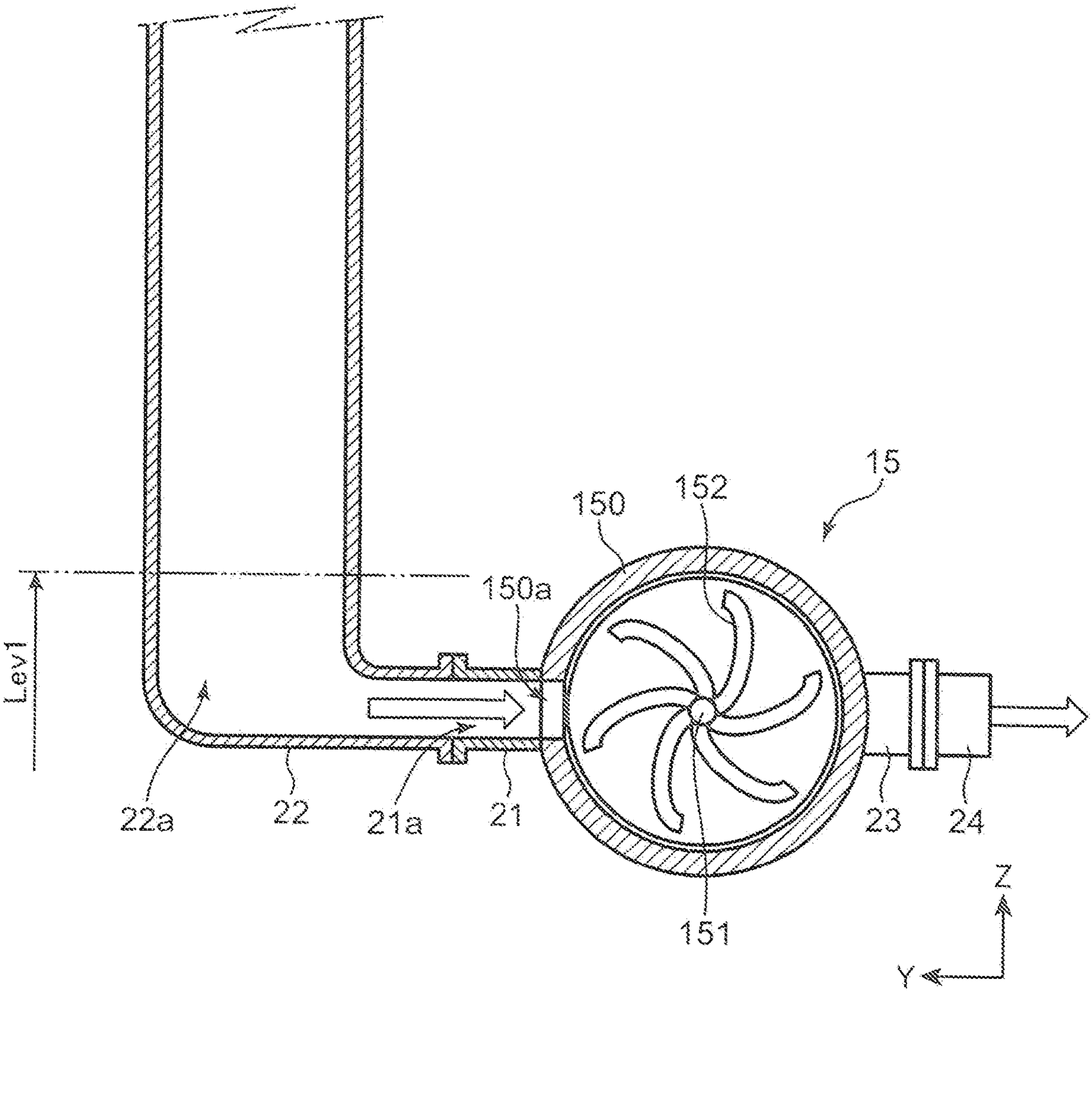


FIG.5

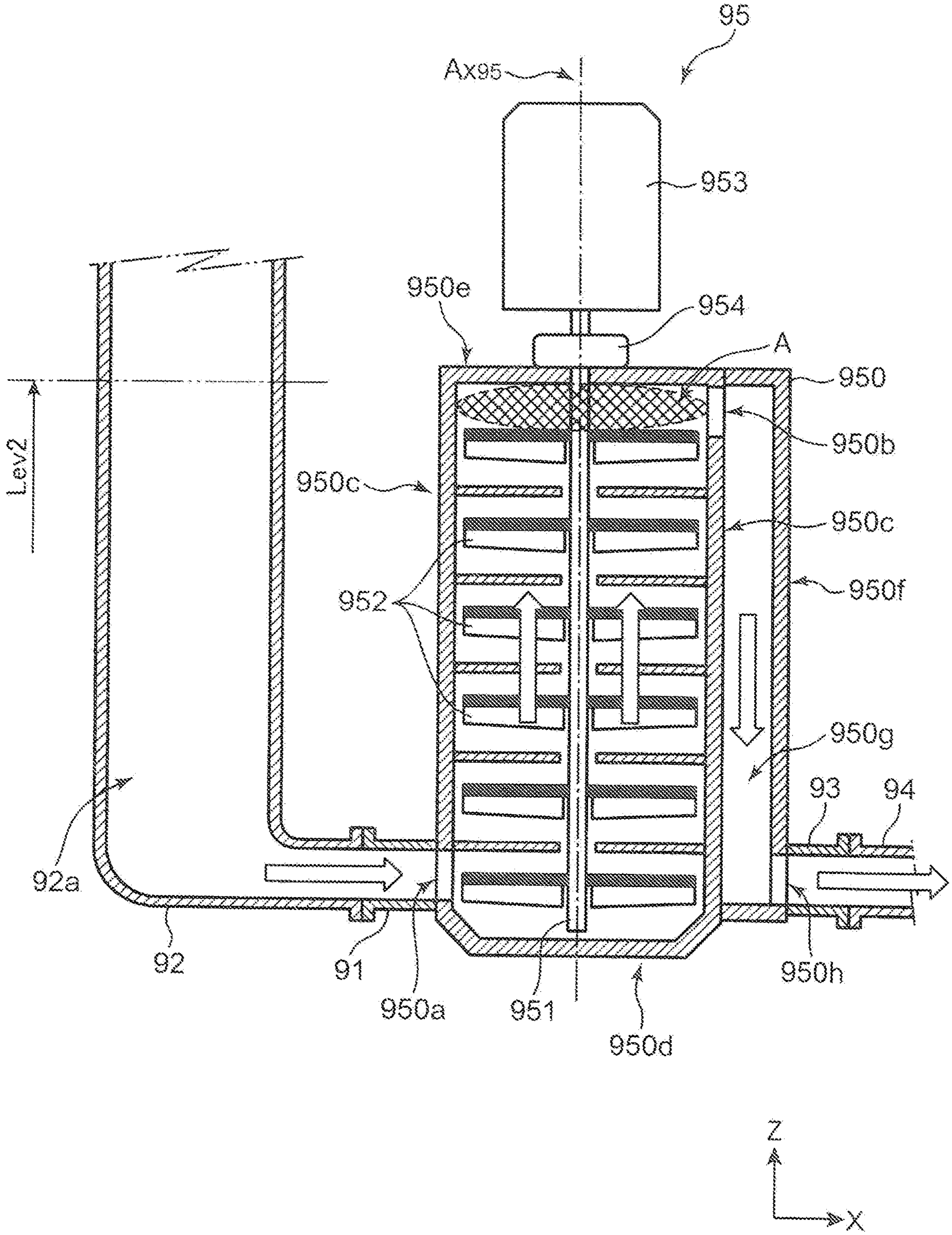

95
Ax95
953
950e
954
A
950
950b
950c
950c
950f
952
950g
93
94
92a
92
91
950a
951
950d
950h
Lev2
Z
X

FIG.6

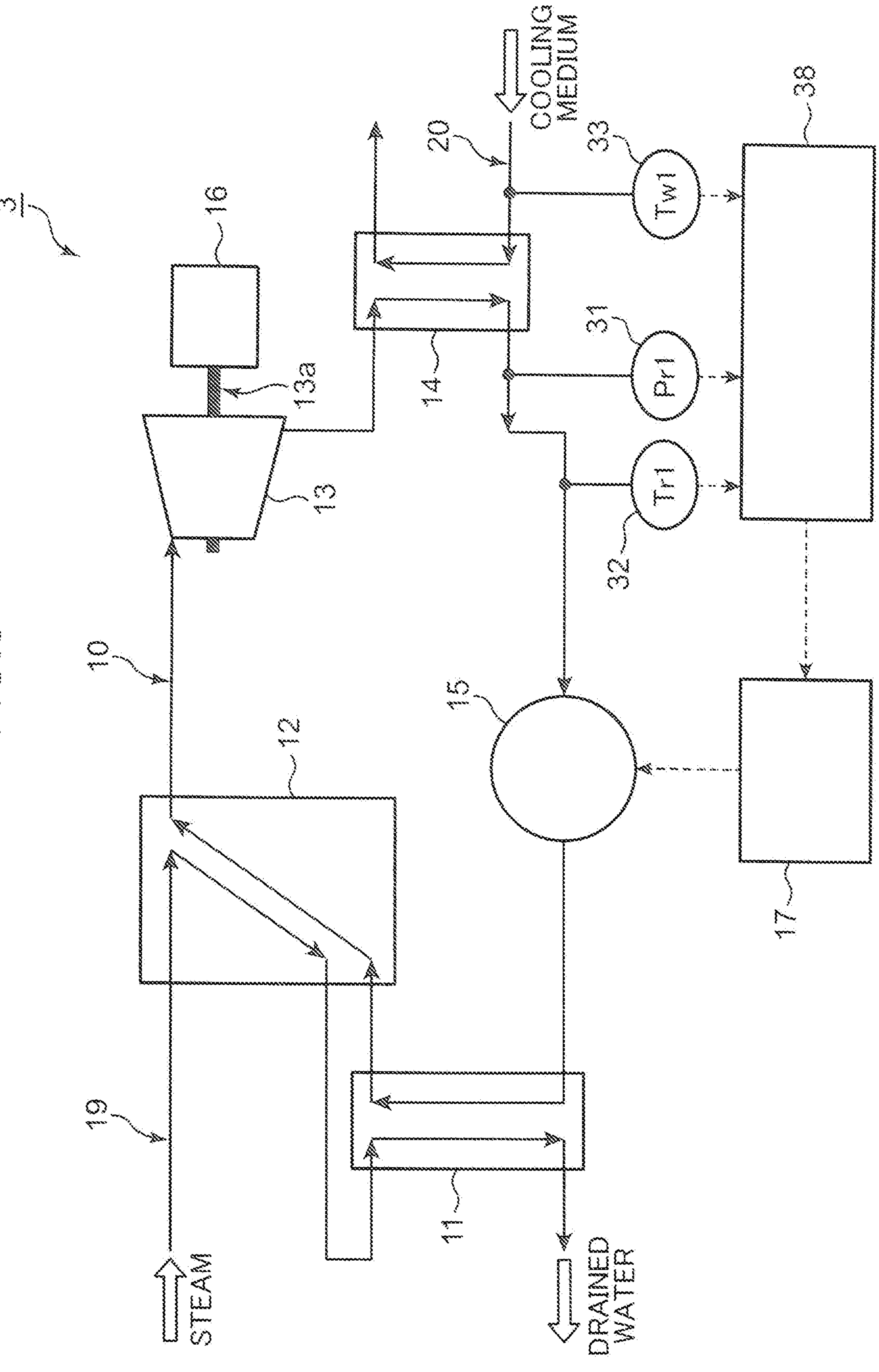

3
16
13a
13
10
12
19
STEAM
11
DRAINED WATER
15
14
20
COOLING MEDIUM
33
Tw1
31
Pr1
32
Tr1
38
17

FIG.7

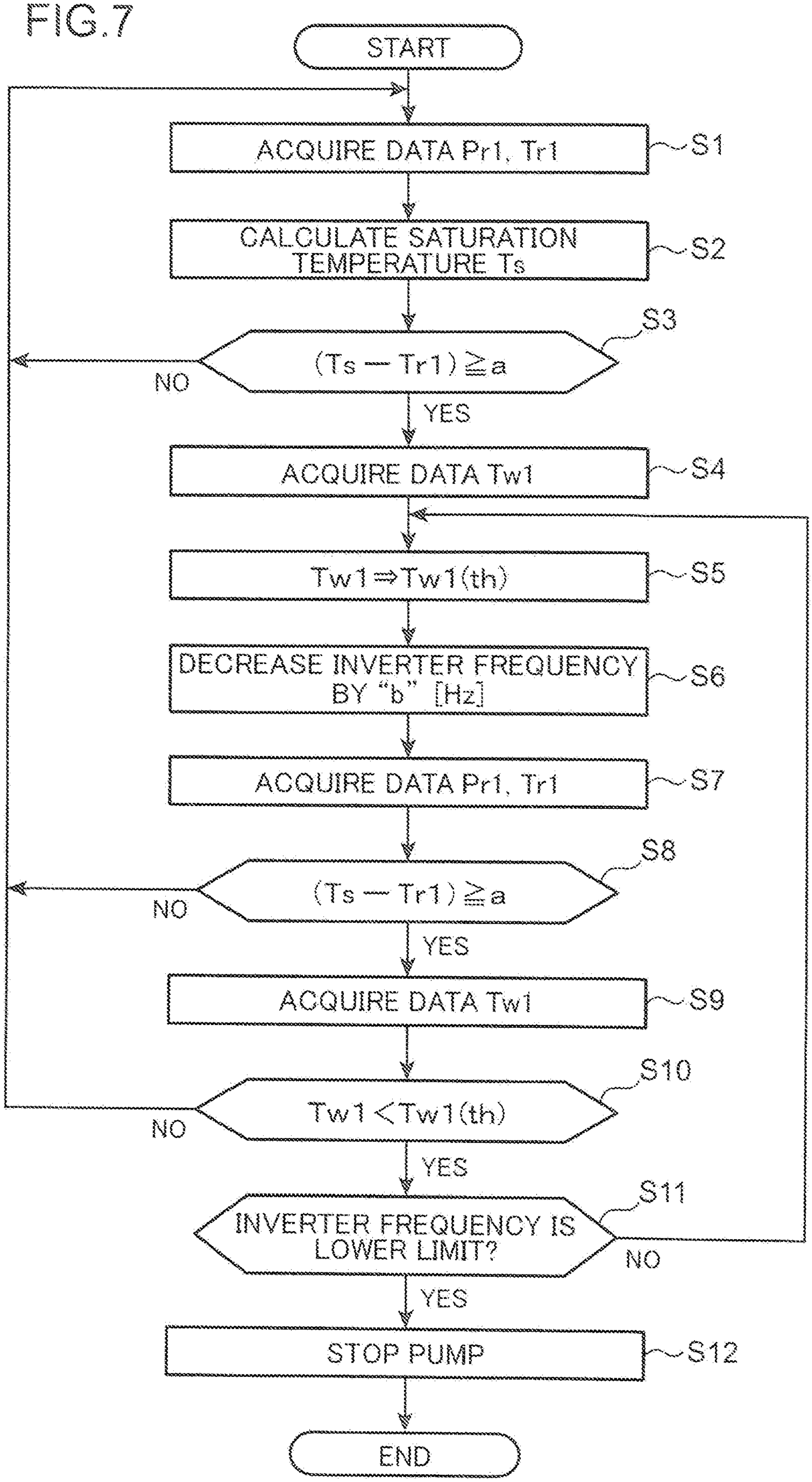
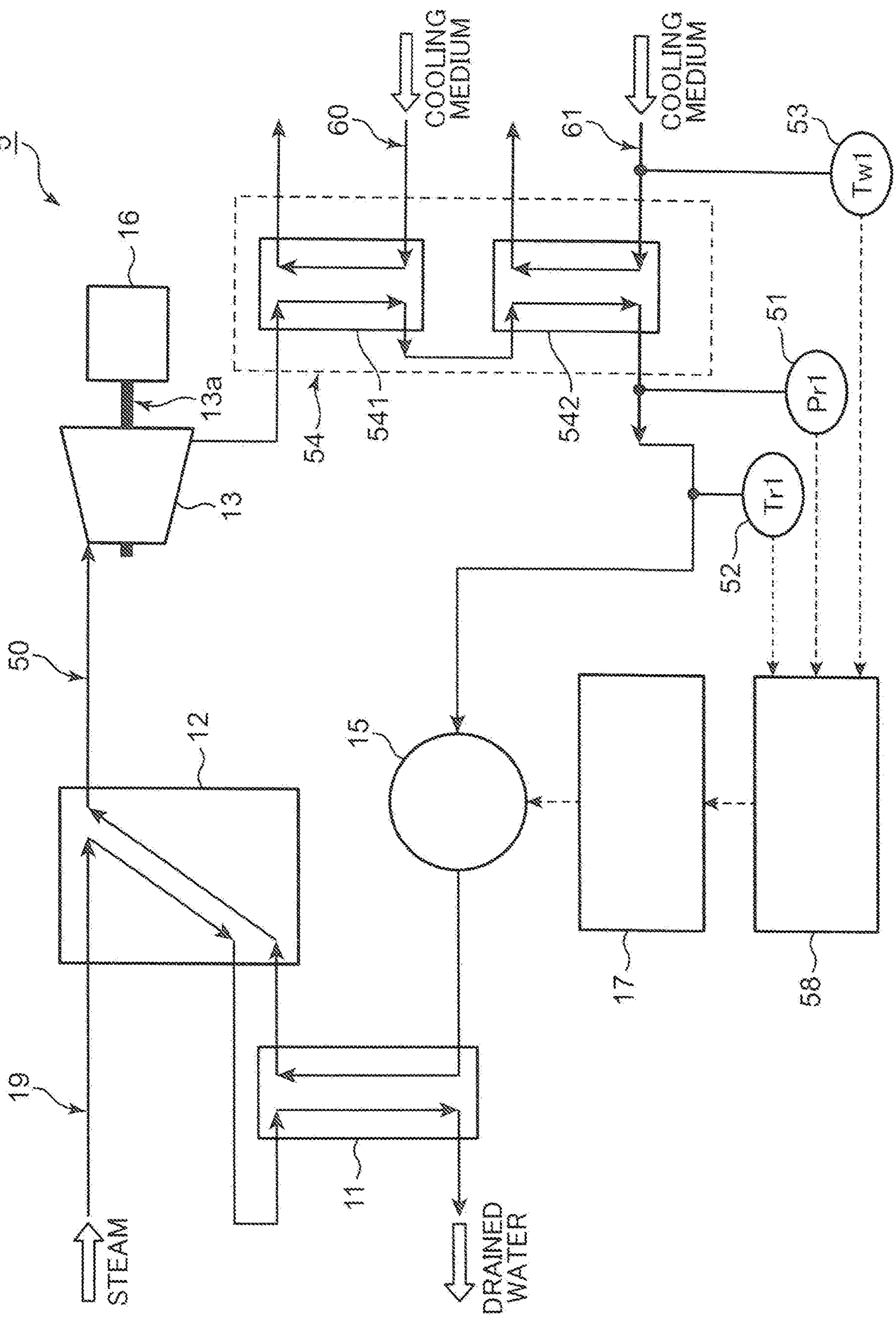

START
ACQUIRE DATA Pr1, Tr1
S1
CALCULATE SATURATION TEMPERATURE Ts
S2
(Ts − Tr1) ≧ a
S3
NO
YES
ACQUIRE DATA Tw1
S4
Tw1 ⇒ Tw1(th)
S5
DECREASE INVERTER FREQUENCY BY "b" [Hz]
S6
ACQUIRE DATA Pr1, Tr1
S7
(Ts − Tr1) ≧ a
S8
NO
YES
ACQUIRE DATA Tw1
S9
Tw1 < Tw1(th)
S10
NO
YES
INVERTER FREQUENCY IS LOWER LIMIT?
S11
NO
YES
STOP PUMP
S12
END

FIG.8


5
16
13a
13
50
12
19
STEAM
11
DRAINED WATER
15
17
58
54
541
542
60
COOLING MEDIUM
61
COOLING MEDIUM
53
Tw1
51
Pr1
52
Tr1

BINARY POWER GENERATION SYSTEM AND STOPPING METHOD FOR SAME

TECHNICAL FIELD

The present invention relates to a binary cycle power generation system and a method for stopping the system, and particularly, relates to a binary cycle power generation system including a multistage centrifugal pump, and a method for stopping the system.

BACKGROUND ART

Study and Development have recently been done to binary cycle power generation systems fulfilling as one of thermal energy recovery systems (e.g., Patent Literature 1). Such a binary cycle power generation system includes an evaporator, an expander, a condenser and a pump arranged in this order in a circulation line of a working fluid, and a power generator is connected to the expander. The evaporator evaporates the working fluid owing to gained steam or warm water. The expander expands the working fluid evaporated in the evaporator. The condenser condenses the working fluid coming from the expander owing to a heat exchange with cooling water.

The binary cycle power generation system having this configuration which uses a working fluid having a boiling point lower than that of water to drive an expander makes it possible to generate power in a lower temperature range than a conventional power generation system which drives an expander directly by steam.

CITATION LIST

Patent Literature

Patent Literature 1: Japanese Unexamined Patent Publication No. 2012-202269

SUMMARY OF INVENTION

However, the binary cycle power generation system according to the conventional technology has a problem that a cavitation occurs in a casing of the pump when the system is stopped in a state that the condenser has a high temperature, and then restarted. Specifically, when the system is stopped in the state that the condenser has a high temperature, the pressure rapidly decreases because the circulation of the working fluid stops, but the temperature in the condenser remains high, so that the working fluid comes into a saturation state. The working fluid at a suction port of the pump provided at a downstream position of the condenser consequently comes into the saturation state.

When the system is restarted and the pump is driven in the saturation state of the working fluid at the suction port of the pump, the working fluid at the suction port comes into a superheated state, so that a cavitation occurs in the casing. The occurrence of the cavitation in the casing of the pump leads to malfunction of the system or damage to the pump.

The present invention has been achieved to solve the above-described problems, and an object of the present invention is to provide a binary cycle power generation system which can prevent a cavitation from occurring in a pump in the restarting of the system.

A binary cycle power generation system according to an aspect of the present invention includes a working fluid

circulation line, an evaporator, an expander, an energy recovery apparatus, a condenser, and a pump.

The working fluid circulation line is a line through which a working fluid circulates.

The evaporator is a structural component which is provided in the working fluid circulation line, and evaporates the working fluid owing to a gained thermal energy.

The expander is a structural component which is provided at a downstream side with respect to the evaporator in the working fluid circulation line, and expands the working fluid coming from the evaporator.

The energy recovery apparatus is a structural component which recovers a kinetic energy generated in the expander.

The condenser is a structural component which is provided at a downstream side with respect to the expander in the working fluid circulation line, and condenses the working fluid coming from the expander owing to a heat exchange with a cooling medium.

The pump is a structural component which is provided at a position downstream of the condenser and upstream of the evaporator in the working fluid circulation line, and causes the working fluid coming from the condenser to go to the evaporator.

The pump includes a casing, a rotary shaft, and impellers.

The casing is hollow and has an end wall at an end in a longitudinal direction.

The rotary shaft is a structural component which has an axis extending in the longitudinal direction, which is supported on the end wall, at least a part of which is in the casing, and which rotates owing to a torque.

The impellers are structural components attached to the rotary shaft one after another in the longitudinal direction.

The pump is arranged in such a way that the axis of the rotary shaft intersects a vertical direction.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a schematic diagram showing an overall configuration of a binary cycle power generation system according to a first embodiment.

FIG. **2** is a schematic cross-sectional side view showing a configuration and arrangement of a pump in the first embodiment.

FIG. **3** is a schematic cross-sectional top view showing the configuration and the arrangement of the pump in the first embodiment.

FIG. **4** is a schematic cross-sectional end view showing the configuration and the arrangement of the pump in the first embodiment.

FIG. **5** is a cross sectional view showing a configuration and an arrangement of a comparative pump.

FIG. **6** is a schematic diagram showing a configuration of a binary cycle power generation system according to a second embodiment.

FIG. **7** is a flowchart showing a control flow executed by a controller in the binary cycle power generation system according to the second embodiment when stopping the system.

FIG. **8** is a schematic diagram showing a configuration of a binary cycle power generation system according to a third embodiment.

DESCRIPTION OF EMBODIMENTS

Hereinafter, embodiments will be described with reference to the accompanying drawings. It should be noted that the embodiments described below each merely represents an aspect of the present invention. Therefore, the present invention should not be limited to the embodiments except for essential configurations.

First Embodiment

1. Overall Configuration

An overall configuration of a binary cycle power generation system **1** according to a first embodiment will be described with reference to FIG. **1**.

As shown in FIG. **1**, the binary cycle power generation system **1** according to the first embodiment includes a working fluid circulation line **10**, a preheater **11**, an evaporator **12**, an expander **13**, a condenser **14**, a pump **15**, a power generator (energy recovery apparatus) **16**, an inverter **17**, and a controller (control unit) **18**.

The working fluid circulation line **10** is a line through which a working fluid circulates. Adopted as the working fluid is a fluid which has a lower boiling point than water and boils at room temperature, for example, a substitute Freon (e.g., HFC 245fa), a mixed liquid of ammonia and water, and an organic substance such as isopentane and isobutane. For instance, HFC 245fa is a medium which has a boiling point of 15.3 [° C.] and evaporates at room temperature.

Each of the preheater **11** and the evaporator **12** is a heat exchanger having the principle of countercurrent devices. Specifically, the preheater **11** and the evaporator **12** cause the working fluid to flow in the opposite direction to a direction in which steam or warm water passes through a steam supply line **19**. The preheater **11** preheats the working fluid, and thereafter the evaporator evaporates the working fluid.

The expander **13** is provided at a downstream position (at a downstream position in the flow direction of the working fluid) of the evaporator **12** in the working fluid circulation line **10**. The expander **13** expands the working fluid coming from the evaporator **12**. Although the details of the expander **13** are not shown in the drawings, a positive displacement screw expander including a pair of male and female screw rotors is adopted as the expander **13** in this embodiment.

The expander **13** has a pair of rotors to be driven owing to an expansion energy of the working fluid coming in a gaseous state. The expander **13** has a rotary shaft **13***a* connected to one of the pair of screw rotors, extending outward, and having an end connected to the power generator **16**.

The power generator **16** serves as an energy recovery apparatus in the binary cycle power generation system **1** according to this embodiment. The power generator **16** generates power owing to a torque produced by the expander **13**. In this manner, the thermal energy of the supplied steam is acquired.

The condenser **14** is provided at a downstream position of the expander **13** in the working fluid circulation line **10**. The condenser **14** is a countercurrent-type heat exchanger in which the working fluid coming in the gaseous state from the expander **13** and cooling medium (e.g., cooling water) passing through a cooling medium circulation line **20** flow in the opposite directions and exchange heat with each other. The condenser **14** cools and condenses the working fluid coming in the aforementioned manner, and the condensed working fluid goes to the pump **15** in the liquid state.

The pump **15** is provided at a position downstream of the condenser **14** and upstream of the preheater **11** in the working fluid circulation line **10**. The pump **15**, which will be described in detail later, includes a multistage centrifugal pump having a motor and a plurality of impellers rotated by the motor. The pump **15** pressurizes the working fluid having entered therein to reach a predetermined value, and then causes the pressurized working fluid to flow into the preheater **11**.

The inverter **17** is a device for driving the motor of the pump **15** at a variable speed. The inverter **17** changes the speed of the motor by changing the frequency of power supplied to the motor of the pump **15**.

The controller **18** outputs to the inverter **17** an instruction of changing the speed of the pump **15** in accordance with input information.

2. Configuration and Arrangement of Pump **15**

A configuration and an arrangement of the pump **15** in the binary cycle power generation system **1** according to this embodiment will be described with reference to FIGS. **2** to **4**. FIG. **2** is a schematic cross-sectional side view showing the configuration and the arrangement of the pump **15**. FIG. **3** is a schematic cross-sectional top view showing the configuration and the arrangement of the pump **15**. FIG. **4** is a schematic cross-sectional end view showing the configuration and the arrangement of the pump **15**.

As shown in FIGS. **2** and **3**, the pump **15** includes a casing **150**, a rotary shaft **151**, a plurality of impellers **152**, a motor (drive source) **153**, and a bearing **154**.

The casing **150** has a peripheral wall **150***c* forming a hollow cylinder, and an end wall **150***d* and another end wall **150***e* at the opposite ends in a longitudinal direction. As shown in FIGS. **2** and **3**, the casing **150** has a cylindrical shape which is longer in the longitudinal direction (X direction) than in a radial direction (Y, Z direction).

The rotary shaft **151** has an axis Ax_{15} extending in the X direction (horizontal direction). The rotary shaft **151** has an end extending outward through the end wall **150***e* of the casing **150** on the right in the X direction. The end of the rotary shaft **151** extending outward from the casing **150** is connected to a drive shaft **153***a* of the motor **153** serving as a drive source.

The bearing **154** is attached to an outer surface of the end wall **150***e* of the casing **150**, and supports the rotary shaft **151** in a state that the axis Ax_{15} is kept in a horizontal posture (posture in the X direction). In other words, one end of the rotary shaft **151** is supported on the end wall **150***e* in this embodiment. However, both ends of the rotary shaft **151** may be supported respectively on the end wall **150***d* and the end wall **150***e*.

Although the pump **15** is arranged in such a way that the Ax_{15} of the rotary shaft **151** extends in the horizontal direction in the binary cycle power generation system **1** according to this embodiment, the Ax_{15} of the rotary shaft **151** may permissibly intersect a vertical direction (Z direction) at other angles. For example, the axis Ax_{15} of the rotary shaft **151** may intersect the vertical direction (Z direction) at an angle of 75° or more to less than 90°.

The plurality of impellers **152** are attached to a part of the rotary shaft **151** that is accommodated in the casing **150** one after another in the X direction. The plurality of impellers **152** rotate integrally with the rotary shaft **151** owing to the torque of the motor **153**.

As shown in FIG. **3**, the peripheral wall **150***c* of the casing **150** is formed with a suction port **150***a* and a discharge port **150***b*. The suction port **150***a* is formed in the left of the peripheral wall **150***c* (closer to the end wall **150***d*) in the X direction. The discharge port **150***b* is formed in the right of the peripheral wall **150***c* (closer to the end wall **150***e*) in the X direction.

As shown in FIG. **4**, the suction port **150***a* of the pump **15** is connected with a pipe **22** via a suction port pipe **21**, and the discharge port **150***b* (not shown in FIG. **4**) is connected to a pipe **24** via a discharge port pipe **23**.

The working fluid coming in the liquid state from the condenser **14** is introduced into the casing **150** of the pump **15** after passing through an inside passage **22***a* of the pipe **22** and an inside passage **21***a* of the suction port pipe **21**. The introduced working fluid advances in a rearward direction of FIG. **4** on the paper while being pressurized by the rotating impellers **152**. Thereafter, the pressurized working fluid passes through the discharge port pipe **23** and the pipe **24**, and goes to the preheater **11**.

Here, as shown in FIG. **2**, the pump **15** in this embodiment is arranged in the horizontal posture in such a way that the axis Ax_{15} of the rotary shaft **151** extends in the horizontal direction (X direction). This arrangement sufficiently enables the working fluid to reach the discharge port **150***b* while being pressurized by the pump **15**, even when a liquid surface of the working fluid is at a low level or Level **1** as shown in FIG. **4**.

3. Configuration and Arrangement of Comparative Pump **95**

A configuration and an arrangement of a comparative pump **95** will be described with reference to FIG. **5** in comparison with the above-described configuration and arrangement of the pump **15**.

As shown in FIG. **5**, the comparative pump **95** similarly includes a casing **950**, a rotary shaft **951**, a plurality of impellers **952**, a motor **953**, and a bearing **954**. The rotary shaft **951**, the impellers **952**, the motor **953**, and the bearing **954** among the components have no structural change from the rotary shaft **151**, the impellers **152**, the motor **153**, and the bearing **154** respectively of the above-described pump **15**. Thus, the description for these components will be omitted.

The casing **950** of the pump **95** includes a peripheral wall **950***c* forming a hollow cylinder, an end wall **950***d* and another end wall **950***e* at the opposite ends in a longitudinal direction, and an outer wall **950***f* which extends along a part of the peripheral wall **950***c* to define a discharge passage **950***g* with the part of the peripheral wall **950***c* therebetween.

The peripheral wall **950***c* of the casing **950** is formed with a suction port **950***a* at a lower position thereof (closer to the end wall **950***d*) in a Z direction, and is formed with a discharge port **950***b* at an upper position thereof (closer to the end wall **950***e*) in the Z direction. The outer wall **950***f* of the casing **950** is formed with an outer discharge port **950***h* at a lower position thereof in the Z direction.

As shown in FIG. **5**, the comparative pump **95** is arranged in a vertical posture in such a way that an axis Ax_{95} of the rotary shaft **951** extends in the Z direction (vertical direction). In this arrangement, the suction port **950***a* is at a lower position and the discharge port **950***b* is at a higher position of the casing **950** in the Z direction.

The suction port **950***a* is connected with a pipe **92** via a suction port pipe **91**, and the outer discharge port **950***h* is connected with a pipe **94** via the discharge pipe **93**.

The working fluid coming from the condenser is introduced into the casing **950** from the suction port **950***a* after passing through an inside passage **92***a* of the pipe **92** and a suction port pipe **91**. The introduced working fluid then advances upward in the Z direction while being pressurized by the rotating impellers **952**. Thereafter, the pressurized working fluid flows out from the discharge port **950***b*, advances in the discharge passage **950***g*, further flows out from the outer discharge port **950***h*, passes through the discharge port pipe **93** and the pipe **94**, and goes to the preheater.

4. Advantageous Effects

Hereinafter, advantageous effects of the binary cycle power generation system **1** according to the first embodiment will be described in comparison with a system including the comparative pump **95** shown in FIG. **5**.

4-1. First Embodiment

As described with reference to FIGS. **2** to **4**, the pump **15** is arranged in the horizontal posture in such a way that the axis Ax_{15} of the rotary shaft **151** extends in the substantially horizontal direction in the binary cycle power generation system **1** according to the first embodiment. The binary cycle power generation system **1** thus can prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the binary cycle power generation system **1** more effectively than a system including the comparative pump **95** arranged in the vertical posture in such a way that the Ax_{95} of the rotary shaft **951** extends in the vertical direction (Z direction).

Specifically, the binary cycle power generation system **1** according to the first embodiment including the pump **15** arranged in the horizontal posture allows the working fluid to flow from the suction port **150***a* to the discharge port **150***b* more smoothly in the restarting of the system than the system including the comparative pump arranged in the horizontal posture, even when the liquid surface of the working fluid is at a low level or Level **1**.

In this manner, the working fluid cooled in the condenser is allowed to smoothly enter into the casing **150** of the pump **15** even in stopping of the binary cycle power generation system **1**, so that the working fluid is kept from coming into the saturation state around the suction port **150***a*. The binary cycle power generation system **1** having this configuration in the first embodiment can prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system **1**.

As a result, the binary recycle power generation system **1** can prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system **1**, and therefore can further avoid malfunction.

Moreover, as described above, the working fluid is allowed to smoothly flow into the casing **150** of the pump **15** in this embodiment in the restarting of the system **1**. Hence, it is possible to prevent a gas from accumulating in the casing **150**.

Therefore, the binary cycle power generation system **1** according to this embodiment can avoid damage attributed to the accumulating gas to the pump.

The binary cycle power generation system **1** according to the first embodiment consequently can avoid damage accompanied by the restarting of the system **1** to the bearing **154** of the pump **15**, thereby achieving a high and long-term reliability.

4-2. Comparative Example

In contrast, as described with reference to FIG. **5**, the comparative pump **95** is arranged in the vertical posture in such a way that the axis Ax_{95} of the rotary shaft **951** extends in the vertical direction (Z direction). In this arrangement, the liquid surface of the working fluid is required to be at a high level or Level **2** as shown in FIG. **5** in the inside passage **92***a* of the pipe **92** for the purpose of filling the casing **950** with the working fluid to start the pump **95**.

If the liquid surface of the working fluid is at a lower level than Level **2** in the inside passage **92***a* of the pipe **92** and the working fluid is insufficient to fill an inside of the casing **950**, a cavitation may occur in the casing **950** when starting the pump **95** in the restarting of the system. The occurrence of the cavitation in the casing **950** may cause a gas to accumulate in an upper region (denoted by an arrow A) in the inside of the casing **950** in the Z direction.

The accumulating gas in the upper region in the inside of the casing **950** in the Z direction as described above is likely to damage, for example, the bearing **954** due to the heat generated by the rotating rotary shaft **951**, the bearing **954** facing the upper region containing the accumulating gas in the Z direction across the end wall **950***e* outside.

Furthermore, such gas accumulation is likely to occur when starting the pump **95** in the binary cycle power generation system including the comparative pump **95** and thus hinder the working fluid from smoothly flowing out from the discharge port **950***b*, which results in malfunction of the system.

Second Embodiment

1. Overall Configuration

An overall configuration of a binary cycle power generation system **3** according to a second embodiment will be described with reference to FIG. **6**. The same structural components shown in FIG. **6** as those of the binary cycle power generation system **1** according to the first embodiment are given with the same reference signs, and the descriptions about these components will be omitted hereafter.

As shown in FIG. **6**, the binary cycle power generation system **3** according to this embodiment includes a working fluid circulation line **10**, a preheater **11**, an evaporator **12**, an expander **13**, a condenser **14**, a pump **15**, a power generator **16**, an inverter **17**, and a controller (control unit) **38**. The binary cycle power generation system **3** according to this embodiment further includes a pressure detector **31**, a temperature detector **32**, and a cooling temperature detector **33**.

The pressure detector **31** is a detector which is provided in a portion between the condenser **14** and the pump **15** in the working fluid circulation line **10**, and detects a pressure of the working fluid at an outlet of the condenser **14**.

The temperature detector **32** is a detector which is provided in a portion between the condenser **14** and the pump **15** in the working fluid circulation line **10** similarly to the pressure detector **31**, and detects a temperature of the working fluid at the outlet of the condenser **14**.

The cooling temperature detector **33** is a sensor which is provided at a supply port to the condenser **14** in a cooling medium circulation line **20** connected to the condenser **14**, and detects a temperature of a cooling medium (e.g., cooling water) supplied to the condenser **14**.

Like the controller **18**, the controller **38** outputs a signal to the inverter **17** and controls driving of the motor **153** of the pump **15**. The controller **38** differs from the controller **18** in the first embodiment in that the controller **38** receives the pressure information from the pressure detector **31**, the temperature information from the temperature detector **32**, and the cooling temperature information from the cooling temperature detector **33** one after another, and further utilizes the received information to control the driving (and stopping) of the motor **153**.

2. Control Executed by Controller **38** when Stopping System

Control executed by the controller **38** when stopping the binary cycle power generation system **3** according to this embodiment will be described with reference to FIG. **7**.

As shown in FIG. **7**, the controller **38**, when stopping the system, firstly acquires pressure information Pr**1** and temperature information Tr**1** of the working fluid at the outlet of the condenser **14** in the working fluid circulation line **10** respectively from the pressure detector **31** and the temperature detector **32** (step S**1**). The controller **38** may acquire the pressure information Pr**1** and the temperature information Tr**1** timelessly or only when stopping the system. In this embodiment, the controller **38** is configured to acquire the pressure information Pr**1** and the temperature information Tr**1** one after another.

Next, the controller **38** calculates a saturation temperature Ts from the acquired pressure information (a pressure of the working fluid at the outlet of the condenser **14**) Pr**1** (step S**2**). Subsequently, the controller **38** calculates a supercooling degree (Ts−Tr**1**) or a difference between the calculated saturation temperature Ts and the acquired temperature information (a temperature of the working fluid at the outlet of the condenser **14**), and determines whether the supercooling degree (Ts−Tr**1**) is a predetermined (target) value "a" [° C.] or more (step S**3**).

The controller **38** re-executes steps S1 to S3 when the determination in step S3 results in (Ts−Tr**1**)<"a" ("No" in step S3).

It should be noted that the predetermined value of the supercooling degree "a" [° C.] in the determination in step S**3** falls within a range of, for example, 1.0 [° C.] to 2.0 [° C.].

Conversely, the controller **38** acquires, from the cooling temperature detector **33**, cooling temperature information (a temperature of the cooling medium supplied to the condenser **14**) Tw**1** (step S**4**) when the determination results in (Ts−Tr**1**)≥"a" relative to the saturation temperature ("Yes" in step S**3**). The controller **38** further temporally stores the acquired cooling temperature information Tw**1** as Tw**1** (th) (step S**5**), and outputs to the inverter **17** an instruction of decreasing an inverter frequency of power supplied to the motor **153** of the pump **15** by a predetermined value "b" [Hz] (step S**6**), thereby reducing the rotational speed of the motor **153** of the pump **15** by 120× b/p (rpm). The reference sign "p" denotes the pole number of the motor **153**.

The predetermined value "b" [Hz] falls within a range of, for example, 0.5 to 1.0 [Hz] in this embodiment.

Thereafter, the controller **38** reacquires pressure information Pr**1** and temperature information Tr**1** of the working fluid at the outlet of the condenser **14** in the working fluid circulation line **10** at the time of having decreased the inverter frequency (step S**7**). The controller **38** recalculates a supercooling degree (Ts−Tr**1**) or a difference between a saturation temperature Ts and the acquired temperature information Tr**1** by using the acquired temperature information Tr**1**, and determines whether the recalculated supercooling degree (Ts−Tr**1**) is the predetermined (target) value "a" [° C.] or more (step S**8**). When the determination in step S**8** results in (Ts−Tr**1**)≥"a" ("Yes" in step S**8**), the controller **38** acquires cooling temperature information Tw**1** of the cooling medium (step S**9**), and determines whether the acquired cooling temperature information Tw**1** is lower than the cooling temperature information Tw**1** (th) stored in step **5**, that is, lower than the cooling temperature information Tw**1** acquired before decreasing the inverter frequency (step S**10**).

The controller **38** returns to step S1 and re-executes the control when the determination in either step S**8** or S**10** results in "No".

Meanwhile, the controller **38** subsequently determines whether the inverter frequency of the inverter **17** is less than a lower limit (step S11) when both the determinations in the steps S8 and S10 result in "Yes". The controller **38** stops the driving of the motor **153** of the pump **15** (step S12) when the inverter frequency of the inverter **17** is determined to be less than the lower limit ("Yes" in step S11).

The controller **38** repeats steps S5 to S11 when the inverter frequency is determined to be the lower limit or more in step S11 ("No" in step S11).

As described above, the controller **38** in this embodiment reduces the rotational speed of the motor **153** of the pump **15** in a stepwise way, while keeping at the predetermined value "a" [° C.] or more the supercooling degree (Ts−Tr1) based on the acquired three pieces of information (pressure information Pr1, temperature information Tr1, and cooling temperature information Tw1), until the system stops.

3. Advantageous Effects

The binary cycle power generation system **3** according to this embodiment permits the controller **38** to, by executing the control shown in FIG. **7**, reduce the rotational speed of the motor **153** of the pump **15** in a stepwise or gradual way, while keeping at the predetermined value "a" [° C.] or more the supercooling degree (Ts−Tr1) or a difference between the saturation temperature Ts and the temperature Tr1 of the working fluid at the outlet of the condenser **14** and reducing the pressure of the working fluid at the outlet of the condenser **14**, until the system stops. Therefore, the system **3** can prevent a cavitation from occurring in the pump **15** in the restarting of the system **3**, and further avoid malfunction.

As described above, if the pump abruptly stops in a state that the condenser has a high temperature, the pressure of the working fluid at a downstream position of the condenser rapidly decreases, but the temperature in the condenser remains high, so that the working fluid comes into a saturation state. The working fluid at the suction port of the pump comes consequently into the saturation state. The working fluid at the suction port of the pump comes into a superheated state when the system is restarted in this situation. As a result, a cavitation is likely to occur.

In contrast, the motor **153** of the pump **15** in the binary cycle power generation system **3** according to this embodiment is configured to stop the system by reducing the rotational speed of the motor **153** of the pump **15** in a stepwise or gradual way, while keeping at the predetermined value "a" [C°] or more the supercooling degree (Ts−Tr1) or the difference between the saturation temperature Ts and the temperature Tr1 of the working fluid at the outlet of the condenser **14** and reducing the pressure of the working fluid at the outlet of the condenser **14**. This configuration makes it possible to keep the working fluid at the suction port **150***a* of the pump **15** from coming into the superheated state in the stopping of the system **3**, and prevent a cavitation from occurring in the casing **150** of the pump **15** in the restating of the system **3**.

Furthermore, the binary cycle power generation system **3** according to this embodiment including the pump **15** arranged in the horizontal posture in the same manner as the first embodiment allows the working fluid to flow from the suction port **150***a* to the discharge port **150***b* more smoothly in the restarting of the system **3** than the system including the comparative pump arranged in the vertical direction, even when the liquid surface of the working fluid is at a low level or Level **1**. Accordingly, the binary cycle power generation system **3** according to this embodiment can prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system **3** as well as the binary cycle power generation system **1**.

Consequently, the binary cycle power generation system **3** according to this embodiment can reliably prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system **3**, and further avoid malfunction and damage to the pump **15** by adopting the above-described control by the controller **38** in combination with the same configuration and arrangement of the pump **15** according to the first embodiment.

Third Embodiment

1. Configuration

An overall configuration of a binary cycle power generation system **5** according to a third embodiment will be described with reference to FIG. **8**. The same structural components shown in FIG. **8** as those of the binary cycle power generation systems **1** and **3** respectively according to the first and second embodiments are given with the same reference signs, and the descriptions about these components will be omitted hereafter.

As shown in FIG. **8**, the binary cycle power generation system **5** according to this embodiment includes a working fluid circulation line **50**, a preheater **11**, an evaporator **12**, an expander **13**, a condenser **54**, a pump **15**, a power generator **16**, an inverter **17**, and a controller (control unit) **58**. The binary cycle power generation system **5** further includes a pressure detector **51** and a temperature detector **52** provided at an outlet of the condenser **54** in the working fluid circulation line **50**, and a cooling temperature detector **53** which detects a temperature of a cooling medium supplied to the condenser **54**.

The pressure detector **51**, the temperature detector **52**, and the cooling temperature detector **53** in the binary cycle power generation system **5** according to this embodiment basically have the same functions as the pressure detector **31**, the temperature detector **32**, and the cooling temperature detector **33** in the binary cycle power generation system **3** according to the second embodiment.

As shown in FIG. **8**, the condenser **54** in this embodiment includes a first condensing part **541** and a second condensing part **542** connected with each other in series in the working fluid circulation line **50**. The first condensing part **541** is provided at an upstream position and the second condensing part **542** is provided at a downstream position in the working fluid circulation line **50**.

The first condensing part **541** is supplied with a cooling medium (e.g., cooling water) via a cooling medium circulation line **60**, and the second condensing part **542** is supplied with a cooling medium (e.g., cooling water) via a cooling medium circulation line **61**.

The first condensing part **541** and the second condensing part **542** cool the working fluid by using the cooling medium in the binary cycle power generation system **5** according to this embodiment even in stopping of the system.

The pressure detector **51** and the temperature detector **52** are provided at the outlet of the second condensing part **542** in the working fluid circulation line **50**. In other words, the pressure detector **51** and the temperature detector **52** are provided at the outlet of the condenser **54** in the working fluid circulation line **50**.

The cooling temperature detector **53** is provided in the cooling medium circulation line **61** to the second condensing part **542** provided at a downstream position in the working fluid circulation line **50**, and detects a temperature of the cooling medium supplied to the second condensing part **542**.

Like the second embodiment, the controller **58** is configured to stop the system by reducing a rotational speed of a motor **153** of the pump **15** in a stepwise way while keeping at a predetermined value "a" [° C.] or more a supercooling degree (Ts−Tr**1**) or the difference between the saturation temperature Ts and the temperature Tr**1** of the working fluid at the outlet of the condenser based on acquired three pieces of information (pressure information Pr**1**, temperature information Tr**1**, and cooling temperature information Tw**1**), until the system stops. The controller **58** performs the same control as shown in FIG. **7**.

2. Advantageous Effects

The binary cycle power generation system **5** according to this embodiment, as well as the second embodiment, permits the controller **58** to reduce the rotational speed of the motor **153** of the pump **15** in a stepwise, while keeping at the predetermined value "a" [° C.] or more the supercooling degree (Ts−Tr**1**) calculated based on the temperature Tr**1** of the working fluid at the outlet of the condenser **54**, until the system stops. Accordingly, the system **5** can prevent a cavitation from occurring in the pump **15** in the restarting of the system **5**, and further avoid malfunction.

Moreover, the binary cycle power generation system **5** according to this embodiment including the pump **15** arranged in the horizontal posture can prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system **5** in the same manner as the first and second embodiments.

Furthermore, the binary cycle power generation system **5** according to this embodiment including the condenser **54** constituted by the first condensing part **541** and the second condensing part **542** connected with each other in series in the working fluid circulation line **50** makes it possible to more efficiently cool the working fluid to go to the pump **15**. In other words, the binary cycle power generation system **5** according to this embodiment permits the first condensing part **541** and the second condensing part **542** to condense the working fluid coming from the expander **13** in two stages respectively.

In this manner, it is possible to easily keep at the predetermined value or more the supercooling degree of the working fluid in the pump **15** when stopping the system, and adjust the supercooling degree of the working fluid at the suction port **150***a* of the pump **15** to an effective net positive suction head (NPSH) or more in the restarting of the system **5**.

Hence, the second condensing part **542** of the condenser **54** in this embodiment serves as a supercooler, and therefore is preferential to stop the system while keeping at the predetermined value "a" [° C.] or more the supercooling degree (Ts−Tr**1**) calculated from a saturation temperature Ts and a temperature Tr**1** of the working fluid at the outlet of the condenser **54**.

Consequently, the binary cycle power generation system **5** according to this embodiment can reliably prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system and further avoid malfunction and damage to the pump **15** by adopting the above-described control by the controller **58** when stopping the system, in the same manner as the second embodiment, in combination with the same configuration and arrangement of the pump **15** in the first and second embodiments.

Modifications

Although the steam is supplied to the evaporator **12** via the steam supply line **19** in the first to third embodiments, the present invention should not be limited thereto. For example, warm water or an exhaust gas may be supplied to the evaporator **12**.

Alternatively, an oil having a specified temperature may be supplied to the evaporator **12**.

Although the preheater **11** and the evaporator **12** are provided between the pump **15** and the expander **13** in the working fluid circulation line **10**, **50** in the first to third embodiments, the present invention should not be limited thereto. For example, only the evaporator may be provided between the pump and the expander in the working fluid circulation line.

Although the power generator **16** serving as an exemplary energy recovery apparatus is adopted in the first to third embodiments, the present invention should not be limited thereto. For example, a compressor which compresses a gas or a liquid owing to a gained thermal energy is adoptable.

Although the inverter frequency is decreased to reduce the rotational speed of the motor **153** of the pump **15** in the second and third embodiments, the present invention should not be limited thereto. For example, a control of reducing an applied voltage in addition to the decreasing of the inverter frequency, i.e., a control based on an adjustable voltage adjustable frequency (AVAF), is adoptable.

Moreover, the rotational speed of the motor **153** of the pump **15** is reduced in a gradual way in accordance with a decrease in the clock frequency for the control of the controller **38**, **58** in the second and third embodiments. The technical scope of the present invention should cover the features that a rotational speed of a motor of a pump is reduced in a stepwise way, and that the rotational speed is reduced in a gradual way.

Although the pump **15** is arranged in such a way that the axis Ax_{15} of the rotary shaft **151** extends in the horizontal direction in each of the binary cycle power generation systems **1**, **3**, **5** according to the first to third embodiments, the present invention should not be limited thereto. Specifically, the Ax_{15} of the rotary shaft **151** of the pump **15** may permissibly intersect a vertical direction (Z direction) at other angles in the present invention. For example, the axis Ax_{15} of the rotary shaft **151** may intersect the vertical direction (Z direction) at an angle of 75° or more to less than 90°. This arrangement makes it possible to prevent a cavitation from occurring in the casing **150** of the pump **15** in the restarting of the system more effectively than the arrangement of the comparative pump **95** where the axis Ax_{95} of the rotational shaft **951** extends in the vertical direction as shown in FIG. **5**.

Although six impellers **152** are attached to the rotary shaft **150** in the pump **15** in the first to third embodiments, the present invention should not be limited thereto. Two to five, or seven or more impellers may be attached to the rotary shaft.

Although the motor **153** is adopted as a drive source of the pump **15** in the first to third embodiments, the present invention should not be limited thereto. For example, an internal combustion engine such as a gasoline engine and a diesel engine, a gas turbine, or an actuator driven owing to an air pressure or a hydraulic pressure is adoptable. Furthermore, it is not necessarily required to include a motor as a structural component of the pump. Instead, the pump may be driven by a torque from an external drive source.

Although a cantilever structure that the one end of the rotary shaft **151** of the pump **15** is supported is adopted in the first to third embodiments, the present invention should not be limited thereto. A both-end holding structure may be adopted.

Although the controller **38**, **58** is configured to execute the above-described control in addition to the arrangement of the pump **15** in the second and third embodiments, the present invention should not be limited thereto. For example, the comparative pump **95** shown in FIG. **5** is adoptable in the system. Even in this adoption, it may be possible to substantially suppress occurrence of a cavitation in restarting of the system by way of execution of the control by the controller as shown in FIG. **7**.

However, as described above with reference to FIGS. **2** to **5**, the arrangement where the axis Ax_{15} of the rotary shaft **151** of the pump **15** intersects the vertical direction (Z direction) is advantageous in that a cavitation can be kept from occurring in restarting of the system.

Moreover, another type of pump other than the centrifugal pump may be adopted in the execution of the control in the second and third embodiments. For example, a gear pump, a vane pump, or a positive displacement pump such as a screw pump is adoptable.

Although each of the pressure detector **31**, **51**, the temperature detector **32**, **52**, and the cooling temperature detector **33**, **53** is singly provided in the second and third embodiments, the present invention should not be limited thereto. For example, two or more detectors may be respectively provided to calculate average values thereof and further execute the control by using the average values, thereby enabling the control to be more precise.

Although a countercurrent-type heat exchanger is used as a heat exchanger for each of the preheater **11**, the evaporator **12**, the condenser **14**, **54** in the first to third embodiments, the present invention should not be limited thereto. For example, a parallel flow-type heat exchanger or a cross flow-type heat exchanger is adoptable.

ASPECTS OF PRESENT INVENTION

A binary cycle power generation system according to an aspect of the present invention includes a working fluid circulation line, an evaporator, an expander, an energy recovery apparatus, a condenser, and a pump.

The working fluid circulation line is a line through which a working fluid circulates.

The evaporator is a structural component which is provided in the working fluid circulation line, and evaporates the working fluid owing to a gained thermal energy.

The expander is a structural component which is provided at a downstream side with respect to the evaporator in the working fluid circulation line, and expands the working fluid coming from the evaporator.

The energy recovery apparatus is a structural component which recovers a kinetic energy generated in the expander.

The condenser is a structural component which is provided at a downstream side with respect to the expander in the working fluid circulation line, and condenses the working fluid coming from the expander owing to a heat exchange with a cooling medium.

The pump is a structural component which is provided at a position downstream to the condenser and upstream to the evaporator in the working fluid circulation line, and causes the working fluid coming from the condenser to go to the evaporator.

The pump includes a casing, a rotary shaft, and impellers.

The casing is hollow and has an end wall at an end in a longitudinal direction.

The rotary shaft is a structural component which has an axis extending in the longitudinal direction, which is supported on the end wall, at least a part of which is in the casing, and which rotates owing to a torque.

The impellers are structural components attached to the rotary shaft one after another in the longitudinal direction.

The pump is arranged in such a way that the axis of the rotary shaft intersects a vertical direction.

The binary cycle power generation system according to this aspect includes the pump arranged in such a way that the axis of the rotary shaft intersects the vertical direction. Hence, the binary cycle power generation system according to this aspect can prevent a cavitation from occurring in the casing of the pump in the restarting of the system more effectively than a conventional system including a pump arranged in such a way that an axis of a rotary shaft extends in a vertical direction.

Specifically, the arrangement of the pump where the axis of the rotary shaft intersects the vertical section enables the working fluid to flow in the casing in the restarting of the system more smoothly than the arrangement of the pump where the axis of the rotary shaft extends in the vertical direction. The working fluid is cooled in the condenser even in the stopping of the system and the cooled working fluid flows in the casing of the pump, so that the working fluid is kept from coming into the saturation state around the suction port. In this way, it is possible to prevent a cavitation from occurring in the casing of the pump in the restarting of the system.

Consequently, the binary cycle power generation system according to this aspect can prevent a cavitation from occurring in the casing of the pump in the restarting of the system, and therefore ensure to cause the working fluid to go to the evaporator, and further avoid malfunction.

As described above, the pump in this aspect makes it possible to suppress occurrence of a cavitation in the restarting, and therefore prevent a gas from accumulating and further reliably avoid damage thereto in the restarting. In other words, the binary cycle power generation system according to this aspect including the pump arranged in such a way that the axis of the rotary shaft intersects the vertical direction allows the working fluid to flow more smoothly when starting the pump than the system including the pump arranged in such a way that the axis of the rotary shaft extends in the vertical direction, thereby rapidly cooling the inside of the casing. In this manner, the system according to this aspect can suppress occurrence of a cavitation and prevent the gas from accumulating, and thus avoid damage attributed to the accumulating gas to the pump.

Accordingly, the binary cycle power generation system according to this aspect can avoid damage accompanied by the restarting of the system to the pump, thereby achieving a high and long-term reliability.

In a binary cycle power generation system according to another aspect of the present invention having the above-described configuration, the pump is arranged in such a way that the axis of the rotary shaft intersects the vertical direction at an angle of 75° to 90°.

The binary cycle power generation system according to this aspect is effective to prevent a cavitation due to the working fluid from occurring in the pump in the restarting of system by way of the arrangement of the pump where the axis of the rotary shaft intersects the vertical direction at an angle of 75° to 90°. In this aspect, specifically, the pump is arranged in a lying state in the substantially horizontal direction (in a substantially horizontal state), and similarly, the flow passages of the working fluid in the casing extend in a substantially horizontal direction (in a substantially horizontal state).

In this arrangement, the working fluid is allowed to smoothly flow in the casing of the pump in the restarting of the system even in a situation that the liquid surface of the working fluid is at a low level and the inside of the pump is not always filled with the working fluid when the system is stopped. Accordingly, as described above, the system can prevent a cavitation from occurring in the casing of the pump, and further avoid malfunction and damage to the pump.

A binary cycle power generation system according to still another aspect of the present invention having the above-described configuration further includes a controller which controls driving of the pump, wherein the controller reduces a rotational speed of a motor of the pump in a stepwise or gradual way, while keeping at a predetermined value or more a supercooling degree calculated based on a saturation temperature and a temperature of the working fluid between the condenser and the pump in the working fluid circulation line, and then stops the system.

The binary cycle power generation system according to this aspect is configured to reduce the rotational speed of the motor of the pump in a stepwise or gradual way, while keeping at the predetermined value or more a supercooling degree based on the saturation temperature and the temperature of the working fluid at the outlet of the condenser, and then stop the system. Therefore, the system can suppress occurrence of a cavitation in the restarting of the system, and further avoid malfunction.

Meanwhile, if the pump is stopped in a state that the condenser has a high temperature, the pressure of the working fluid at a downstream position of the condenser rapidly decreases, but the temperature in the condenser remains high, so that the working fluid comes into a saturation state. The working fluid at the suction port of the pump comes into a superheated state when the system is restarted in this situation. As a result, a cavitation is likely to occur in the casing of the pump.

In contrast, the binary cycle power generation system according to this aspect is configured, as described above, to reduce the rotational speed of the motor of the pump in a stepwise or gradual way, while keeping at the predetermined value or more a supercooling degree calculated from the saturation temperature and the temperature of the working fluid at the outlet of the condenser, until the system stops. Accordingly, it is possible to avoid the superheated state at the suction port of the pump when stopping the system, and further prevent a cavitation from occurring in the casing of the pump in the restarting of the system.

A binary cycle power generation system according to further another aspect of the present invention having the above-described configuration additionally includes a pressure detector, a temperature detector, and a cooling temperature detector.

The pressure detector is a detector which is provided in a portion between the condenser and the pump in the working fluid circulation line, and detects a pressure of a working fluid in the specific portion.

The temperature detector is a detector which is provided in the portion between the condenser and the pump in the working fluid circulation line, and detects a temperature of the working fluid in the portion.

The cooling temperature detector is a detector which is provided in a supply line of the cooling medium to the condenser, and detects a temperature of the cooling medium in the supply line.

In this aspect, the controller sequentially executes the following operations:

a detection information reception: receiving temperature information from the temperature detector, pressure information from the pressure detector, and cooling temperature information from the cooling temperature detector one after another,

a calculation: calculating a saturation temperature Ts from the pressure information (an acquired pressure of the working fluid at the outlet of the condenser);

a determination: determining whether a supercooling degree (Ts−Tr**1**) that is a difference between the saturation temperature Ts and a temperature Tr**1** of the working fluid at the outlet of the condenser is a predetermined value “a” or more;

a rotational speed reduction: reducing a rotational speed of a motor of the pump by a predetermined value when the determination results in affirmation; and

a cooling temperature comparison: comparing cooling temperature information (temperatures of the cooling medium) before and after the execution of the rotational speed reduction.

In this aspect, the controller repeats the rotational speed reduction and the cooling temperature comparison when the cooling temperature comparison results in that the cooling temperature information (a temperature of the cooling medium) after the execution of the rotational speed reduction is lower than the cooling temperature information (another temperature of the cooling medium) before the execution of the rotational speed reduction.

In this aspect, the specific control operations executed by the controller are defined to stop the pump in the stepwise or gradual way, while keeping at the predetermined value “a” or more the supercooling degree (Ts−Tr**1**) or a difference from the temperature Tr**1** of the working fluid at the outlet of the condenser. The controller executing the above-described operations makes it possible to suppress the superheated state at the suction port of the pump when stopping the system, and further prevent a cavitation from occurring in the pump in the restarting of the system.

In a binary cycle power generation system according to still further another aspect of the present invention having the above-described configuration, the condenser includes a first condensing part and a second condensing part connected with each other in series, the first condensing part being provided at an upstream position and the second condensing part being provided at a downstream position in the working fluid circulation line, and the cooling temperature detector is provided in a supply line of the cooling medium to the second condensing part.

The condenser in the binary cycle power generation system according to this aspect is constituted by the first condensing part and the second condensing part connected with each other in series. In this aspect, in other words, the first condensing part and the second condensing part condense the working fluid coming from the expander in two stages respectively.

In this manner, it is possible to easily keep at the predetermined value or more the super cooling degree of the working fluid in the pump when stopping the system, and adjust the super cooling degree of the working fluid at the suction port of the pump to an effective net positive suction head (NPSH) or more in the restarting of the system.

Consequently, the binary cycle power generation system according to this aspect can further reliably prevent a cavitation from occurring in the pump in the restarting of the system.

In a method for stopping a binary cycle power generation system according to an aspect of the present invention, the binary cycle power generation system includes a working fluid circulation line, an evaporator, an expander, an energy recovery apparatus, a condenser, a pump, a temperature detector, a pressure detector, and a cooling temperature detector.

The working fluid circulation line is a line through which a working fluid circulates.

The evaporator is a structural component which is provided in the working fluid circulation line, and evaporates the working fluid owing to a gained thermal energy.

The expander is a structural component which is provided at a downstream position of the evaporator in the working fluid circulation line, and expands the working fluid coming from the evaporator.

The energy recovery apparatus is a structural component which recovers a kinetic energy generated in the expander.

The condenser is a structural component which is provided at a downstream position of the expander in the working fluid circulation line, and condenses the working fluid coming from the expander owing to a heat exchange with a cooling medium.

The pump is a structural component which is provided at a position downstream of the condenser and upstream of the evaporator in the working fluid circulation line, and causes the working fluid coming from the condenser to go to the evaporator.

The pressure detector is a detector which is provided in a portion between the condenser and the pump in the working fluid circulation line, and detects a pressure of the working fluid in the portion.

The temperature detector is a detector which is provided in a portion between the condenser and the pump in the working fluid circulation line, and detects the temperature of the working fluid in the portion.

The cooling temperature detector is a detector which is provided in a supply line of the cooling medium to the condenser, and detects a temperature of the cooling medium in the supply line.

The method for stopping the binary cycle power generation system according to this aspect includes the following steps to be sequentially executed:

a detection information reception step: receiving temperature information from the temperature detector, pressure information from the pressure detector, and cooling temperature information from the cooling temperature detector one after another,

a calculation step: calculating a saturation temperature Ts from the pressure information (an acquired pressure of the working fluid at the outlet of the condenser);

a determination step: determining whether a supercooling degree (Ts−Tr**1**) that is a difference between the saturation temperature Ts and a temperature Tr**1** of the working fluid at the outlet of the condenser is a predetermined value "a" or more;

a rotational speed reduction step: reducing a rotational speed of a motor of the pump by a predetermined value when the determination results in affirmation; and

a cooling temperature comparison step: comparing cooling temperature information (temperatures of the cooling medium) before and after the execution of the rotational speed reduction step.

In this aspect, the rotational speed reduction step and the cooling temperature comparison step are repeated when the cooling temperature comparison results in that the cooling temperature information (a temperature of the cooling medium) after the execution of the rotational speed reduction is lower than the cooling temperature information (another temperature of the cooling medium) before the execution of the rotational speed reduction.

Conclusively, the binary cycle power generation system and the method for stopping the system according to the respective aspects of the present invention can prevent a cavitation from occurring in the pump in the restarting of the system.

The invention claimed is:

1. A binary cycle power generation system comprising:

a working fluid circulation line through which a working fluid circulates;

an evaporator provided in the working fluid circulation line, and configured to evaporate the working fluid owing to a gained thermal energy;

an expander provided at a downstream side with respect to the evaporator in the working fluid circulation line, and configured to expand the working fluid coming from the evaporator;

an energy recovery apparatus configured to recover a kinetic energy generated in the expander;

a condenser provided at a downstream side with respect to the expander in the working fluid circulation line, and configured to condense the working fluid coming from the expander owing to a heat exchange with a cooling medium;

a pump provided at a position downstream to the condenser and upstream to the evaporator in the working fluid circulation line, and configured to cause the working fluid coming from the condenser to go to the evaporator, and

a controller configured to control driving of the pump, wherein

the pump includes:

a hollow casing having an end wall at an end in a longitudinal direction;

a rotary shaft which has an axis extending in the longitudinal direction, which is supported on the end wall, at least a part of which is in the casing, and which rotates owing to a torque; and

a plurality of impellers attached to the rotary shaft one after another in the longitudinal direction,

the axis of the rotary shaft intersecting a vertical direction, and

the controller reduces a rotational speed of a motor of the pump in a stepwise or gradual way, while keeping a supercooling degree at a predetermined value or more, wherein the supercooling degree is calculated based on a difference between a saturation temperature of the working fluid and a temperature of the working fluid at an outlet of the condenser between the condenser and the pump in the working fluid circulation line, until the binary cycle power generation system stops.

2. A binary cycle power generation system according to claim **1**, wherein the axis of the rotary shaft intersects the vertical direction at an angle of 75° to 90°.

3. A binary cycle power generation system according to claim **1**, further comprising:

a temperature detector provided in a portion between the condenser and the pump in the working fluid circulation line and configured to detect a temperature of the working fluid in the portion;

a pressure detector provided in the portion and configured to detect a pressure of the working fluid in the portion;

a cooling temperature detector provided in a supply line of the cooling medium to the condenser, and configured to detect a temperature of the cooling medium in the supply line, wherein the controller is configured to sequentially execute:

a detection information reception of receiving temperature information from the temperature detector, pressure information from the pressure detector, and cooling temperature information from the cooling temperature detector one after another;

a calculation of calculating a saturation temperature Ts from the pressure information;

a determination of determining whether a supercooling degree (Ts−Tr**1**) that is a difference between the saturation temperature Ts and a temperature Tr**1** of the working fluid at the outlet of the condenser is a predetermined value or more;

a rotational speed reduction of reducing a rotational speed of a motor of the pump by a predetermined value when the determination results in affirmation; and

a cooling temperature comparison of comparing cooling temperature information before and after the execution of the rotational speed reduction,

the controller repeating the rotational speed reduction and the cooling temperature comparison when the cooling temperature comparison results in that the cooling temperature information after the execution of the rotational speed reduction is lower than the cooling temperature information before the execution of the rotational speed reduction.

4. A binary cycle power generation system according to claim **3**, wherein

the condenser includes a first condensing part and a second condensing part connected with each other in series, the first condensing part being provided at an upstream position and the second condensing part being provided at a downstream position in the working fluid circulation line, and

the cooling temperature detector is provided in a supply line of the cooling medium to the second condensing part.

5. A method for stopping a binary cycle power generation system, the system including:

a working fluid circulation line through which a working fluid circulates;

an evaporator provided in the working fluid circulation line, and configured to evaporate the working fluid owing to a gained thermal energy;

an expander provided at a downstream side with respect to the evaporator in the working fluid circulation line, and configured to expand the working fluid coming from the evaporator;

an energy recovery apparatus configured to recover a kinetic energy generated in the expander;

a condenser provided at a downstream side with respect to the expander in the working fluid circulation line, and configured to condense the working fluid coming from the expander owing to a heat exchange with a cooling medium;

a pump provided at a position downstream of the condenser and upstream of the evaporator in the working fluid circulation line, and configured to cause the working fluid coming from the condenser to go to the evaporator;

a temperature detector provided in a portion between the condenser and the pump in the working fluid circulation line and configured to detect a temperature of the working fluid in the portion;

a pressure detector provided in the portion and configured to detect a pressure of the working fluid in the portion; and

a cooling temperature detector provided in a supply line of the cooling medium to the condenser, and configured to detect a temperature of the cooling medium in the supply line, wherein

the method, when stopping the system, sequentially execute:

a detection information reception step of receiving temperature information from the temperature detector, pressure information from the pressure detector, and cooling temperature information from the cooling temperature detector one after another;

a calculation step of calculating a saturation temperature Ts from the pressure information;

a determination step of determining whether a supercooling degree (Ts−Tr**1**) that is a difference between the saturation temperature Ts and a temperature Tr**1** of the working fluid at the outlet of the condenser is a predetermined value or more;

a rotational speed reduction step of reducing a rotational speed of a motor of the pump by a predetermined value when the determination in the determination step results in affirmation; and

a cooling temperature comparison step of comparing cooling temperature information before and after execution of the rotational speed reduction step,

the rotational speed reduction step and the cooling temperature comparison step being repeated when the comparison in the cooling temperature comparison step results in that the cooling temperature information after the execution of the rotational speed reduction step is lower than the cooling temperature information before the execution of the rotational speed reduction step.

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